(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 589 517 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 93202674.3

(22) Date of filing: 16.09.93

(51) Int. Cl.5: F02D 41/18, F02D 41/26, F02D 41/04

(30) Priority: 23.09.92 US 948568

(43) Date of publication of application: 30.03.94 Bulletin 94/13

(84) Designated Contracting States: DE FR GB

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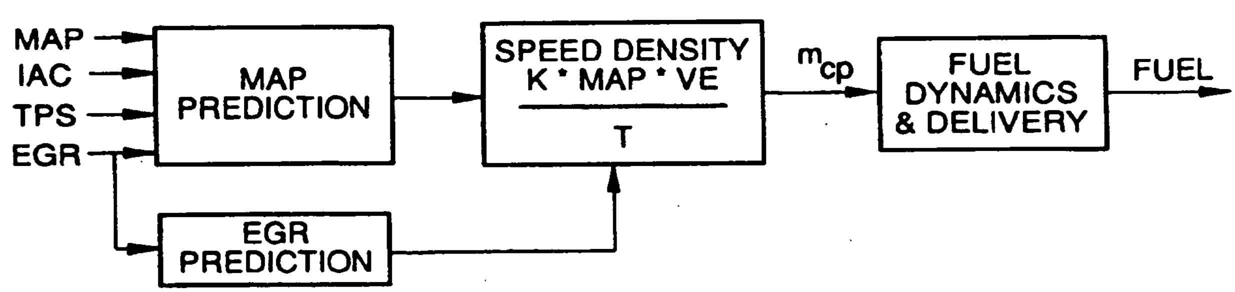
(54) Method of predicting air flow into a cylinder.

(57) A delta model is used to calculate a predicted manifold absolute pressure (MAP) for a future period and the air mass induced in each cylinder is calculated from such a predicted value and used to determine the correct amount of fuel to inject at that period. Several reference pulses generated for each crankshaft revolution establish one or more sets of equally spaced points (62-72) at which measurements are made of the parameters manifold absolute pressure (MAP), throttle position (TPS), exhaust gas recirculation (EGR) and idle air control (IAC). A base value of manifold absolute pressure (MAP) is calculated, trends of changes in the parameters are calculated for each set of points, and weighted values of the trends are summed with the base manifold absolute pressure value to predict a value of (MAP). Alternatively, mass air flow (MAF) is measured as well as the other parameters and mass air per cylinder (MAC) is calculated. Then a base value of mass air per cylinder (MAC) is calculated, trends of changes in the parameters are calculated for each set of points, and weighted values of the trends are summed with the base mass air per cylinder value to predict a value of mass air induced into a cylinder.

FIG - 2



EP 0 589 517 A1

This invention relates to a method of predicting air flow into a cylinder of an engine, for use, for example, in calculating fuel supply.

In automotive engine control, the amount of fuel to be injected is often determined either by measuring the engine speed and the mass air flow (MAF) into the intake manifold, known as the air meter method, or by inferring the air flow from the measurement of engine speed and manifold absolute pressure (MAP), known as the speed-density method. For both approaches, during engine transient operations, the differences between the measured mass air flow, throttle position or manifold absolute pressure and their past values are used to adjust the amount of fuel for the air flow changes. However, as the exhaust emissions standards become more stringent, more effective ways of engine fuel control are needed.

In the speed-density approach, as shown in Figure 1, the measured manifold absolute pressure signal is filtered before it is used for air flow estimation. The result is then used to compute the amount of fuel needed, taking into account the effects of exhaust gas recirculation (EGR). During transient operations, additional calculations are needed to compensate for the transient air and fuel dynamics. These transient control routines are commonly known as acceleration enrichment (AE) and deceleration enleanment (DE). In particular, measured changes in manifold absolute pressure and throttle position (TPS) are multiplied by AE/DE gains and added to the base fuel calculation. They are used to account for errors from both air estimation and fuel dynamics estimation. That is, the changes in throttle position (or manifold absolute pressure) are directly used to calculate the transient fuel requirement.

Due to the differences in the nature of the air and fuel dynamics, the prior acceleration enrichment and deceleration enleanment approaches do not completely reduce the transient air-fuel ratio errors. It is well recognized that the change in throttle position, together with other variables, such as idle air actuator (IAC) and exhaust gas recirculation, causes change in manifold absolute pressure, which in turn changes the amount of air drawn into the cylinders. Fuel dynamics, on the other hand, are strongly influenced by the air flow and the surrounding temperature conditions. Coupling these two significantly different dynamic variables makes accurate control of air-fuel ratio extremely difficult.

The present invention seeks to provide an improved method of predicting air flow.

According to an aspect of the present invention, there is provided a method of predicting air flow into a cylinder of an engine as specified in claim 1.

According to another aspect of the present invention, there is provided a method of predicting air flow into a cylinder of an engine as specified in claim 9.

In a preferred embodiment, an engine position sensor is used to provide several reference pulses in each engine revolution, one set of reference pulses occurring at or near top and bottom dead centres of cylinder position, another set of pulses occurring at a predetermined angular spacing from the dead centre positions, and still other sets may occur at other predetermined spacings from the dead centre positions. At some or all of the reference pulses mass air flow or manifold absolute pressure is measured along with throttle position and optionally other parameters such as exhaust gas recirculation and idle air controller. Then, in this embodiment, changes in the parameters between consecutive points in the same set are calculated to determine a trend of parameter change and each trend is weighted by a gain factor and added to a base value of mass air flow or manifold absolute pressure to obtain a predicted value. That value is then converted to a predicted induced air mass m_{cp} for a cylinder about to receive an injection of fuel, and is useful for the calculation of the required amount of fuel.

An embodiment of the present invention is described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a prior art fuel calculation system;

Figure 2 is a block diagram of an embodiment of fuel calculation system using a predictive manifold absolute pressure algorithm to determine air mass being induced;

Figure 3 is a block diagram of an embodiment of fuel calculation system using a predictive mass air flow algorithm to determine the air mass being induced;

Figure 4 is a schematic diagram of an embodiment of electronic ignition and fuel control system for carrying out the calculations of Figures 2 and 3;

Figure 5 is a diagram showing periods of fuel injection relative to cylinder events for various engine operating conditions;

Figures 6, 7 and 8 are graphs of manifold pressure or mass air flow showing the positions of references pulses used by the control system of Figure 4;

Figures 9 and 10 are graphs showing air mass estimation error without and with prediction, respectively; and

Figure 11 is a flow chart of an embodiment of algorithm for carrying out the calculations of Figures 2 and 3.

The embodiments described below improve the performance of transient fuel control by separating the estimation of the air mass from fuel dynamics, as shown in Figures 2 and 3. First the mass of air induced in a cylinder is predicted for a period in which fuel injection is about to occur and then the required fuel is determined. In Figure 2, the mass of air per cylinder m_{cp} is predicted by first predicting the manifold absolute pressure for the desired period and then applying the speed-density method which requires values for volumetric efficiency (VE) and manifold temperature T. Inputs used for the manifold absolute pressure prediction algorithm are manifold absolute pressure, throttle position, idle air control and exhaust gas recirculation. Depending on the engine application, idle air control and exhaust gas recirculation may not be necessary, thereby simplifying the calculation.

In Figure 3, the mass of air is predicted by first converting mass air flow to mass air calculated (MAC) as a function of engine speed and then doing a prediction of mass per cylinder m_{cp}. The simplest case is shown where only mass air calculated (MAC) and throttle position inputs are required by the prediction algorithm, but in some cases, exhaust gas recirculation and idle air control inputs are needed, as in Figure 2. It is also possible to use both manifold absolute pressure and mass air flow measurements; in that case manifold absolute pressure becomes another input to the prediction algorithm.

Whether manifold absolute pressure or m_{cp} is predicted, the same type of algorithm is used. A similar approach is disclosed in US-A-4,893,244 and in US Patent Application No. 07/733,565 filed on July 22, 1991, entitled "Engine Speed Prediction Method for Engine Control", a copy of which is included in the file held by the European Patent Office. In each case, the cylinder event is divided into several periods by reference pulses produced by an engine position sensor. In these prediction methods, the time interval between pulses is measured, and a trend of interval changes is determined and used to predict a future speed on the basis of a measured interval and the trend, the predicted speed being useful for spark timing or speed control purposes.

A control system for carrying out calculations and implementing system control commands is shown in Figure 4 and includes a microprocessor unit (MPU) 10, an analogue-to-digital converter (ADC) 12, a read only memory (ROM) 14, a random access memory (RAM) 16 and an engine control unit (ECU) 18. The microprocessor unit 10, which may be a microprocessor model MC-6800 manufactured by Motorola Semiconductor Products, Inc. Phoenix, Arizona, receives inputs from a restart circuit 20 and generates a restart signal RST* for initializing the remaining components of the system. The microprocessor unit 10 also provides a read/write signal to control the direction of data exchange and a clock signal CLK to the rest of the system. The microprocessor unit 10 communicates with the rest of the system via a 16-bit address bus 24 and an 8-bit bi-directional data bus 26.

The read only memory 14 contains the program steps for operating the microprocessor unit 10, engine calibration parameters for determining the appropriate ignition dwell time and also ignition timing and fuel injection data in look-up tables which identify as a function of predicted engine speed and other engine parameters the desired spark angle relative to a reference pulse and the fuel pulse width. The microprocessor unit 10 may be programmed in a known manner to interpolate between the data at different entry points if desired.

Based on predicted engine speed, the spark angle is converted to time relative to the latest reference pulse producing the desired spark angle. The desired dwell time is added to the spark time to determine the start of dwell (SOD) time. In the same way, the start of injection (SOI) time is calculated from the fuel pulse width (FPW), the intake valve opening (IVO) time and the predicted speed. Control words specifying a desired start of dwell, spark time, start of injection and fuel pulse width relative to engine position reference pulses are periodically transferred by the microprocessor unit 10 to the engine control unit 18 for generating electronic spark timing signals and fuel injection signals. The engine control unit 18 also receives the input reference pulses (REF) from a reference pulse generator 27 which comprises a slotted ferrous disc 28 driven by the engine crankshaft and a variable reluctance magnetic pickup 29.

In the illustrated example, the slots produce six pulses per crankshaft revolution or three pulses per cylinder event for a four cylinder engine. One extra slot 31 produces a synchronizing signal used in cylinder identification. The reference pulses are also fed to the microprocessor unit 10 to provide hardware interrupts for synchronizing the spark and fuel timing calculations to the engine position.

The EST output signal of the engine control unit 18 controls the start of dwell and the spark timing and is coupled to a switching transistor 30 connected with the primary winding 32 of an ignition coil 34. The secondary winding 36 of the ignition coil 34 is connected to the rotor contact 38 of a distributor 40, which sequentially connects contacts 42 on the distributor cap to respective spark plugs 44, only one of which is illustrated. Of course, the distributor function can be accom-

plished by an electronic circuit, if desired.

The primary winding 32 is connected to the positive side of the vehicle battery 46 through an ignition switch 48. An EFI output signal of the engine control unit 18 is coupled to a fuel injector driver 50 which supplies actuating pulses to fuel injectors 52. To control idle speed, a signal IAC is calculated by the engine control unit with the predicted engine speed in mind, and is coupled to an idle speed actuator 54 to provide an appropriate amount of air to the engine. To establish the position of an exhaust gas recirculation valve actuator 56, the engine control unit estimates the exhaust gas recirculation concentration and the air flow into individual cylinders for good air-fuel ratio control and generates the exhaust gas recirculation signal accordingly.

The inputs to the analogue to digital converter 12 comprise intake manifold temperature T, throttle position TPS manifold-absolute pressure MAP and/or a mass air flow meter output mass air flow. The timing of the reference pulses is used to determine when to measure those parameters. The engine control unit 18 will use them to predict the total amount of air m_{cp} which will flow into each cylinder and then to calculate the amount of fuel to be injected into the cylinders whose intake valve has just opened or is about to open.

To achieve high accuracy in engine fuel control, the time to execute the prediction methods has to be coordinated with the fuel injection scheme. At the selected reference pulses, the throttle position, manifold absolute pressure and engine speed are closely monitored to determine whether fuel injection should be initiated. As shown in Figure 5, there are two main fuel injection events (1 and 2) in one combustion cycle. A third event (3) is used only for a sudden heavy engine acceleration.

The first fuel injection pulse (1) takes place long before the intake valve is open to allow as much residence time as possible for fuel to vaporise. The amount of fuel to be injected in the first injection event (1) is based on the engine speed, fuel requirement, the changes in throttle position, and the injector dynamic limitation. When a relatively small fuel amount is needed, such as at low load, the first injection event (1) is not necessary.

The second injection event (2), taking place just before the intake valve is open, is the most critical one for high accuracy. It is based on the most recent calculated fuel requirement, allowing for the fuel already injected in the first injection. When necessary, such as for the case where the throttle suddenly opens after the second fuel pulsewidth is calculated, a third injection pulse can be deployed to provide additional fuel to minimize the air-fuel ratio errors.

Air Mass Prediction Using Manifold Absolute Pressure

For simplicity, the method using manifold absolute pressure will be taken up first and then the similar method using mass air flow will be described.

In the following description, an illustration is used for a four cylinder engine having only four reference pulses per crankshaft revolution. Figure 6 shows a manifold absolute pressure waveform 60 which generally resembles a sine wave with peaks occurring at both top dead centres (TDC) and bottom dead centres (BDC) of cylinder position. The dots represent reference pulses 62, 64, 66 and 68 marking one set of points at or near the dead centre positions while pulses 70, 72, 74 and 76 make up another set of points which are equally spaced from dead centre positions, for example 60° after dead centre. Thus the four pulses per revolution are not necessarily equally spaced but the pulses or points within each set are equally spaced by 180° of crankshaft rotation for the four cylinder engine application. In the case of a six cylinder engine, the pulses will be spaced by 120°.

A measurement of manifold absolute pressure is recorded at each reference pulse. Each manifold absolute pressure measurement is filtered by averaging it with the previous two measurements to obtain a manifold absolute pressure value for each point. For calculations made at point Q, corresponding to point 72, the manifold absolute pressure value at point 72 is used as a base value MAP_{base} and then a manifold absolute pressure trend is calculated to allow prediction of manifold absolute pressure at a point 180° ahead, that is at point 74. The trend is measured according to changes in manifold absolute pressure, throttle position and often other parameters which take place during the previous 180° period, marked as period A.

Thus, each of the parameters is measured at each point in the set of points 70, 72, and so on. The primary changes are in manifold absolute pressure (MAP) and throttle position (TPS) and are measured by subtracting their values at point 70 from their respective values at point 72 to yield values δMAP_A and δTPS_A. Using this amount of information the predicted MAP_p equation is:

$$MAP_p = MAP_{base} + G1(\delta MAP_A) + G2(\delta TPS_A) \quad - (1)$$

where G1 and G2 are empirically determined prediction gains.

Additional values for measuring trend are obtained from the idle air controller (IAC), exhaust gas

recirculation (EGR) and engine speed (RPM). Their changes over period A are calculated in the same way to obtain δIAC_A, δEGR_A and δRPM_A. The predicted MAP_p at the target point 74 is then:

$$MAP_p = MAP_{base} + G1(\delta MAP_A) + G2(\delta TPS_A) + G3(\delta IAC_A) + G4(\delta EGR_A) + G5(\delta RPM_A) \quad (2)$$

Lines 80, 82 and 84 at the top of Figure 6 and denoted IVO indicate the span of intake valve opening for successive cylinders. Since line 80 indicates that at the calculation time Q a valve is already open for one cylinder, the predicted MAP_p is used to calculate the amount of the third injection pulse, if any, for that cylinder. At the same time, the MAP_p is used to calculate the second injection pulse for the cylinders corresponding to valve openings 82 and 84. When the time reaches point 74, the calculation is repeated using the measurements for the period B to predict manifold absolute pressure for point 76.

Figure 7 shows the same manifold absolute pressure curve 60 but with six reference pulses per crankshaft revolution. This allows another level of prediction terms to be included in the calculation of future manifold absolute pressure. The additional reference pulses provide another set of points 90 - 96 positioned, for example 30° before each dead centre. These points define new periods A1, B1, C1, and so on, which occur 90° ahead of corresponding periods A, B, C........

As in Figure 6, the manifold absolute pressure values are the average of the last three manifold absolute pressure measurements, and a recent manifold absolute pressure value is used as the base manifold absolute pressure value. At point 72, the manifold absolute pressure trend is calculated from the changes of parameters over period A as well as the changes of parameters over period A1. Even the periods between dead centres can be used to provide trend information. Thus, when the measurements from more points are used, the equation for MAP_p has additional weighted trend terms for greater prediction accuracy. If the manifold absolute pressure value at point 72 is chosen to be the base manifold absolute pressure value, the prediction target will be point 74, which is 180° beyond the time of calculation. However if the manifold absolute pressure value at point 92 is chosen as the base manifold absolute pressure value, the prediction target will be point 94 which is 90° beyond the time of calculation. Similarly, the base value can be that at point 64 and the prediction target will then be point 66, which is 120° beyond the calculation time at point 72.

Another example having six reference points per revolution for a four cylinder engine is shown in Figure 8. In Figure 8, the nomenclature is generalized with the points identified as n-1, n, n+1, omitting the values at dead centre points for trend calculations but using them if desired for base manifold absolute pressure values. The prediction equation then becomes:

$$MAP_p(n+q) = MAP(n) + SUM\{ a_i(MAP(n-i) - MAP(n-i-p))\} + SUM\{b_j(TPS(n-j) - TPS(n-j-p))\} + SDM\{c_s(EGR(n-s) - EGR(n-s-p))\} + SUM\{d_t(IAC(n-t) - IAC(n-t-p))\} \quad (3)$$

where n is the cylinder firing event at the time prediction is executed; p is the number of sampling points in one firing event and q is the prediction horizon; a_i, b_j, c_s and d_t are prediction gains and i, j, s and t are numbers from zero up to the terms selected according to the system dynamics. The prediction gains themselves can be functions of the engine operating conditions and are determined empirically for each type of engine. An engine speed (RPM) term may also be added to the prediction equation.

The number of terms used in the above equation should be determined by the system dynamics. That is, the influence of throttle position, exhaust gas recirculation, idle air control and manifold absolute pressure itself on the future manifold absolute pressure. Some engines do not employ exhaust gas recirculation and thus the exhaust gas recirculation term (EGR) does not apply; other engines restrain the rate of change of exhaust gas recirculation so that it is not an important transient factor and the exhaust gas recirculation term (EGR) can be omitted. Due to the throughput limitation of the control unit 18, it may be desirable to reduce the number of terms. In one engine, good results were obtained by reducing the trend terms to two, using only gains a_0 and b_0 to result in equation (1) above. The results obtained for that engine operating over a test manoeuvre lasting for about 165 engine revolutions, are given in Figure 9 which shows the manifold absolute pressure estimation error when no prediction algorithm is used and in Figure 10, which shows the estimation errors when the prediction algorithm is used.

The prediction method is simple and requires little computation. The "delta" (δ) model is selected for prediction because it eliminates steady state errors by inherently providing integrator effects. Thus, it does not need additional mechanisms to compensate for the steady state bias caused by changes in engine operation and vehicle loads. It also has the advantage of maintaining steady state accuracy when the ambient pressure varies as the vehicle is driven through different altitudes.

Given the predicted manifold absolute pressure, the predicted mass of air induced into each cylinder m_{cp} is determined from well known speed

density calculations. In general,

$m_{cp} = K^{*}MAP_{p}{}^{*}VE/T$ (4)

where K is a constant, VE is volumetric efficiency, and T is manifold temperature. The volumetric efficiency VE is a variable empirically determined as a function of engine speed (RPM) and MAP_p. For a given manifold absolute pressure target point, calibration to determine volumetric efficiency begins with steady state engine operation. Volumetric efficiency tables are constructed to match the measured air flow into the cylinders for each of several different engine speeds. Then the parameters used in manifold absolute pressure prediction are obtained under transient operating conditions and additional volumetric efficiency tables can be constructed for those other engine transient conditions such as exhaust gas recirculation and idle air control, as needed.

The desired amount of fuel for each cylinder event is calculated on the basis of the estimated induced air mass per cylinder and the desired air-fuel ratio. The fuel injector parameters are also used to determine the injector signal pulse-width. Finally, the crankshaft location to start the fuel delivery is selected and the corresponding time to open the fuel injector is computed.

A flow chart in Figure 11 illustrates of prediction method for use by the engine controller. When a new reference pulse is detected to have been received at step 100, its crank angle location is identified at step 102, and then manifold absolute pressure, throttle position, idle air control, and exhaust gas recirculation are measured at step 104. Engine speed is calculated at step 106 preferably using an engine speed prediction method disclosed in United States patent application No. 07/733,565. If at step 108 it is determined that it is time to predict manifold absolute pressure, the computation of MAP_p is performed at step 110 following equation (3) to determine manifold absolute pressure at the next target point. With this information, the induced air mass per cylinder is calculated at step 112 and the fuel amount is also calculated at step 114. If transient fuel compensation (a third injection pulse) is deemed to be needed at step 116 that value is calculated at step 118. As is fully set out in the above-mentioned United States application 07/733,565, the fuel injector is controlled to inject the correct fuel amount to the cylinder at step 120.

Air Mass Prediction Using Mass Air Flow

To apply the air mass prediction method to systems using a mass air flow meter, the mass air flow MAC is calculated as MAC = K1*MAF/RPM, where K1 is a constant, as indicated in Figure 3. Then the value MAC is substituted for manifold absolute pressure in the above equation (3) to obtain the predicted air mass per cylinder m_{cp}. Restated in MAC form, equation (3) becomes

$m_{cp}(n+q) = MAC(n) + SUM\{a_i(MAC(n\text{-}i) - MAC(n\text{-}i\text{-}p))\} + SUM\{b_j(TPS(n\text{-}j) - TPS(n\text{-}j\text{-}p))\} + SUM\{c_s(EGR(n\text{-}s) - EGR(n\text{-}s\text{-}p))\} + SUM\{d_t(IAC(n\text{-}t) - IAC(n\text{-}t\text{-}p))\}$ (5)

Thus, the predicted m_{cp} is determined by selecting a recent value of MAC for a base and adding the trend which is calculated on the basis of the change of several parameters over one or more periods, as expressed in equation (5). The primary difference in implementation is that the conversion to per cylinder value is performed first and the predicted value is m_{cp} instead of MAP_p. In equation (5), a previously predicted value $m_{cp}(n)$ can be used as the base instead of MAC(n).

As suggested by Figure 3, one embodiment utilizes both manifold absolute pressure and mass air flow measurements for the prediction of the mass air flow per cylinder m_{cp}. In that event, the equation (5) is further modified by including manifold absolute pressure terms in the trend calculation so the change in manifold absolute pressure per interval affects the trend.

It will thus be seen that for either the speed-density approach or the mass air flow meter approach to measuring the air mass per cylinder, the air mass value can be accurately predicted during transient operating conditions in time to calculate and implement precise fuel injection amounts for the target prediction time.

The disclosures in United States patent application no. 948,568, from which this application claims priority, and in the abstract accompanying this application are incorporated herein by reference.

Claims

1. A method of predicting air flow into a cylinder of an engine including a pressure sensor (MAP) for measuring manifold absolute pressure and a throttle position sensor (TPS); the method comprising the steps of determining values of manifold absolute pressure and throttle position at each point of at least one set of points substantially uniformly spaced from top and bottom dead centre of the cylinder; calculating trends in manifold absolute pressure and throttle position from the determined values at consecutive points in the set; determining a base manifold absolute pressure value; predicting a future manifold absolute pressure

value from the base manifold absolute pressure value and the calculated trends; and predicting the mass of air flow into the cylinder from the predicted future manifold absolute pressure value.

2. A method according to claim 1, wherein for an engine which includes apparatus for producing an exhaust gas recirculation valve signal (EGR) and an idle air control signal (IAC), the method includes the steps of detecting values of exhaust gas recirculation and idle air control at each of the points; and calculating the trends in exhaust gas recirculation and idle air control from their respective values at the most recent points; the step of predicting a future manifold absolute pressure value including using the trends in exhaust gas recirculation and idle air controller.

3. A method according to claim 1 or 2, wherein the step of predicting the mass of air flow into the cylinder comprises the steps of determining volumetric efficiency and manifold temperature; and determining the mass of air flow as a function of the predicted manifold absolute pressure value, the volumetric efficiency and the manifold temperature.

4. A method according to claim 1, 2 or 3, wherein the step of predicting the future manifold absolute pressure value comprises the step of multiplying each calculated trend by a respective gain to form a series of product terms and adding the product terms to the base manifold absolute pressure value.

5. A method according to any preceding claim, wherein the step of determining a base manifold absolute pressure value includes the step of measuring manifold absolute pressure values at or proximate top and bottom dead centre.

6. A method according to any preceding claim, wherein each manifold absolute pressure value is a filtered value of manifold absolute pressure measurements.

7. A method according to claim 6, wherein each filtered manifold absolute pressure value is determined by averaging at least two consecutive manifold absolute pressure measurements.

8. A method according to any preceding claim, wherein the base manifold absolute pressure value is determined from at least the most recent manifold absolute pressure value.

9. A method of predicting air flow into a cylinder in an engine including an air flow sensor (MAF) for measuring mass air flow and a throttle position sensor (TPS); the method comprising the steps of measuring mass air flow at each point of at least one set of points substantially uniformly spaced from top and bottom dead centre; calculating mass air flow per cylinder (MAC) at each point from the measured mass air flow and engine speed; measuring throttle position at each point; calculating trends in mass air flow per cylinder and throttle position from the measurements at consecutive points in the set or sets; determining a base average mass air flow per cylinder value; and predicting air flow into the cylinder from the base mass air flow per cylinder value and the calculated trends.

10. A method according to claim 9, wherein for an engine which includes apparatus for producing a manifold absolute pressure signal (MAP), the method includes the steps of detecting values of manifold absolute pressure at each of the points in the set or sets; and calculating a trend in manifold absolute pressure from the detected values at the most recent points in the set or sets; the step of predicting a future value of mass air flow per cylinder including using the trend in manifold absolute pressure.

11. A method according to claim 9 or 10, wherein for an engine which includes apparatus for measuring absolute manifold pressure (MAP), engine speed, exhaust gas recirculation valve signal (EGR) and idle air control signal (IAC), the method comprises the steps of measuring manifold absolute pressure, exhaust gas recirculation and idle air control at each point of the set or sets of points; calculating trends in manifold absolute pressure, exhaust gas recirculation, and idle air control from the measurements at the consecutive points; air flow into the cylinder being predicted from the base mass air flow per cylinder value and the calculated trends by multiplying each calculated trend by a respective gain to form a series of product terms and adding the product terms to the base mass air flow per cylinder value.

12. A method according to claim 9, 10 or 11, wherein the step of determining a base mass air flow per cylinder value includes the step of measuring mass air flow values substantially at top and bottom dead centre.

13. A method according to claim 9, 10, 11 or 12, wherein the base mass air flow per cylinder

value comprises a previously predicted value of air mass into the cylinder.

14. A method according to any preceding claim, wherein the set or sets of points includes a first set of points having a first substantially uniform spacing relative to top and bottom dead centre and a second set of points having a second substantially uniform spacing relative to top and bottom dead centre; and the step of calculating the trends in each value includes determining the change in each value between successive points in each of the first and second sets.

15. A method according to claim 14, wherein the points of the second set of points are at or proximate top and bottom dead centre.

16. A method according to any preceding claim, wherein the trend in each value is calculated in dependence upon a difference in said value measured at two previous points of the first and second sets of points.

17. A method according to any preceding claim, wherein the step of calculating the trend in each value includes the step of determining the change in said value over a period between a most recent point and a second most recent point as well as the change in said value over at least one period ending prior to the most recent point.

FIG - 1
(PRIOR ART)

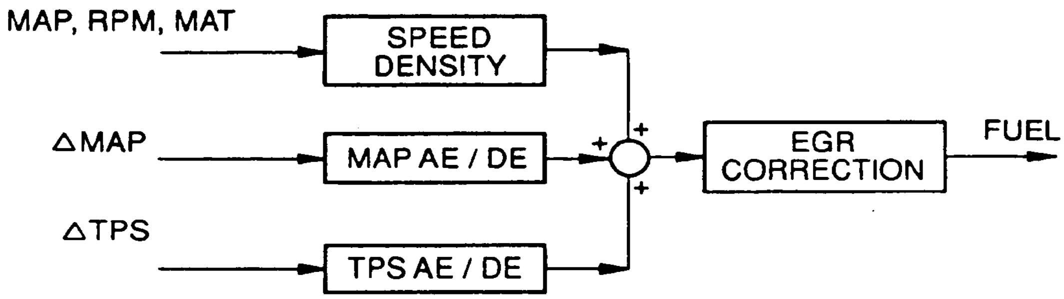


FIG - 2

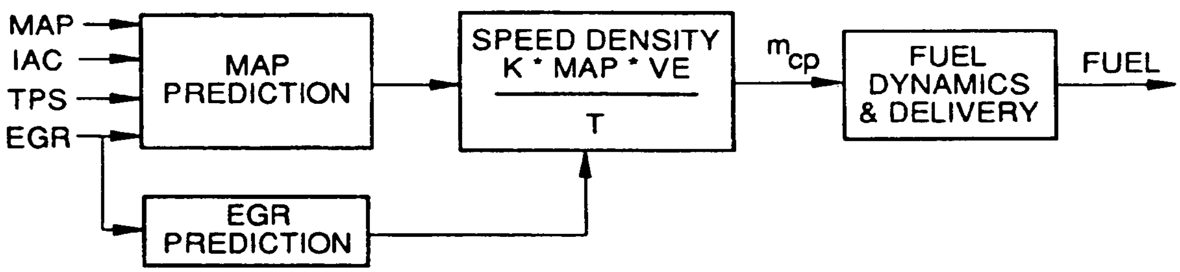


FIG - 3

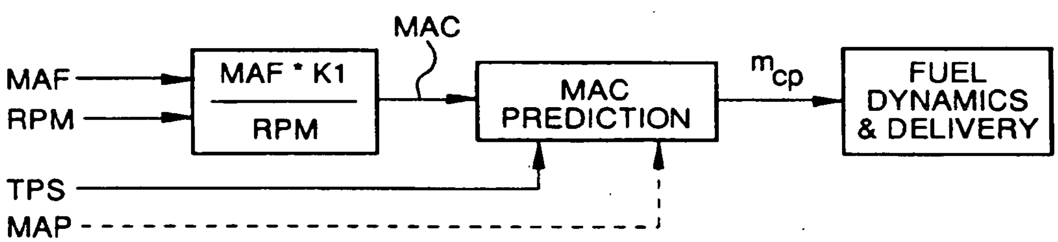
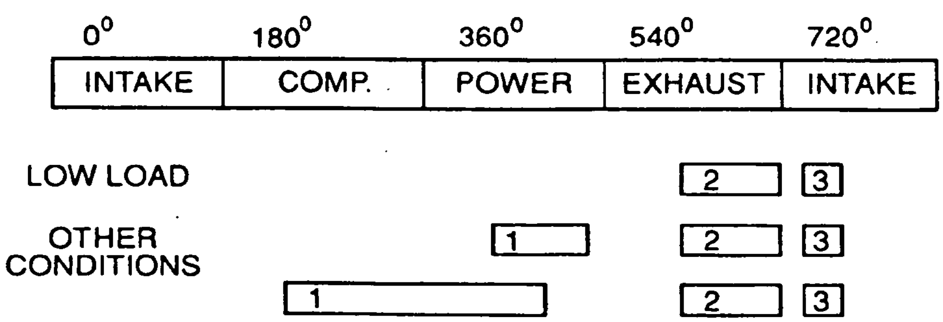
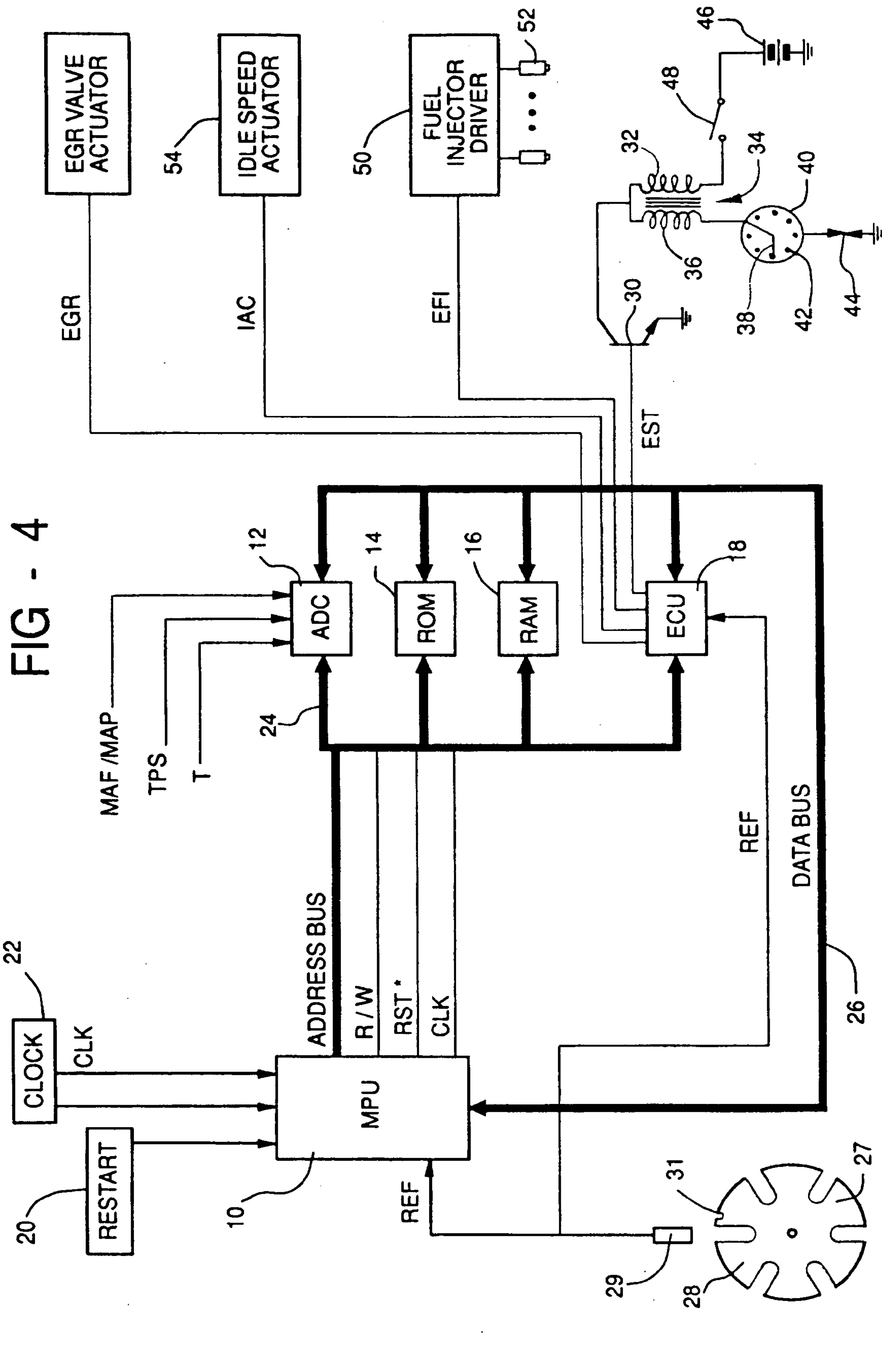


FIG - 5





EGR VALVE ACTUATOR
IDLE SPEED ACTUATOR
FUEL INJECTOR DRIVER
54
50
52
46
48
32
34
40
36
30
38
42
44
EGR
IAC
EFI
EST
ADC
ROM
RAM
ECU
12
14
16
18
MAF /MAP
TPS
T
24
ADDRESS BUS
R / W
RST *
CLK
REF
DATA BUS
26
22
CLOCK
CLK
MPU
RESTART
20
10
REF
31
27
29
28

FIG - 4

FIG - 6

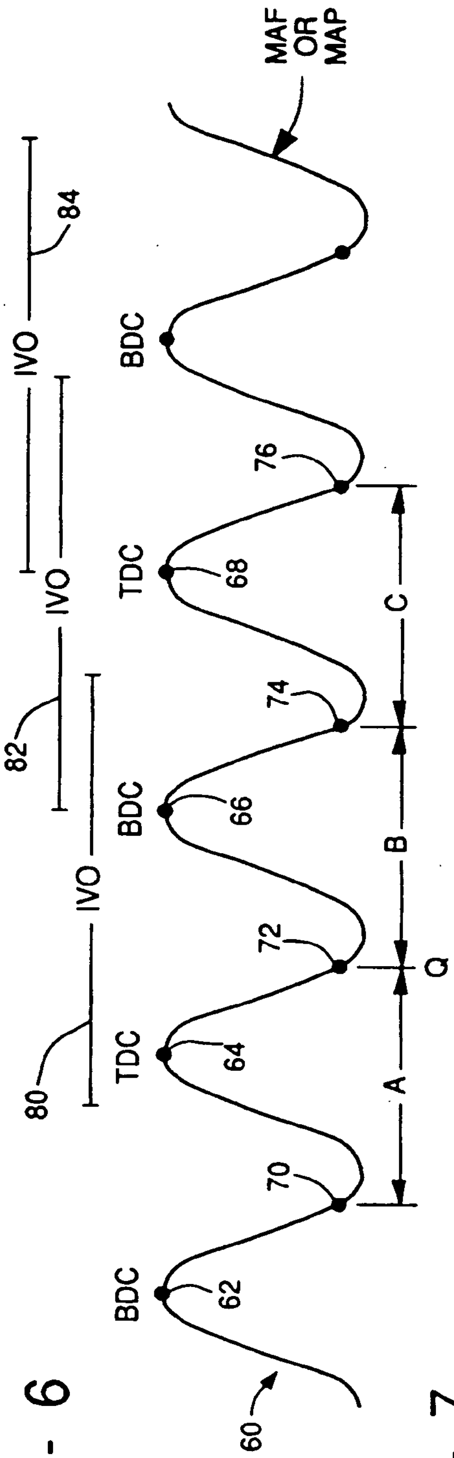


FIG - 7

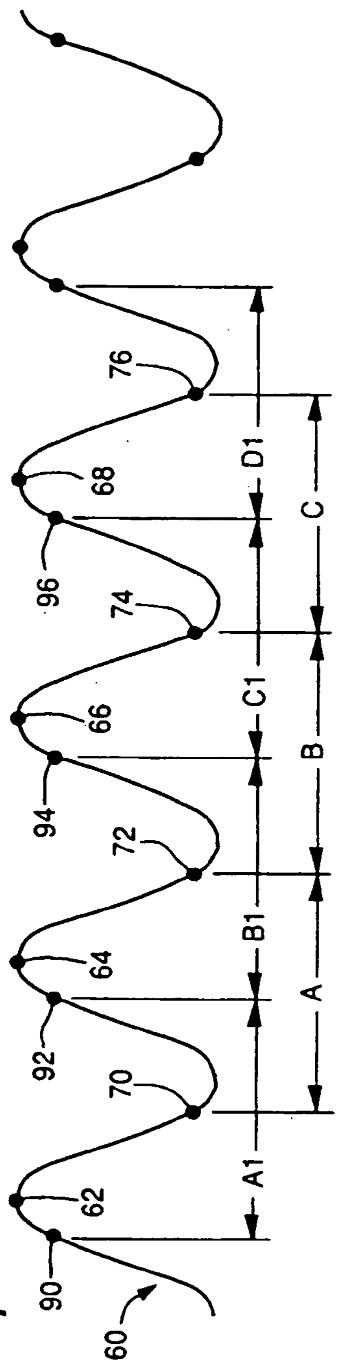


FIG - 8

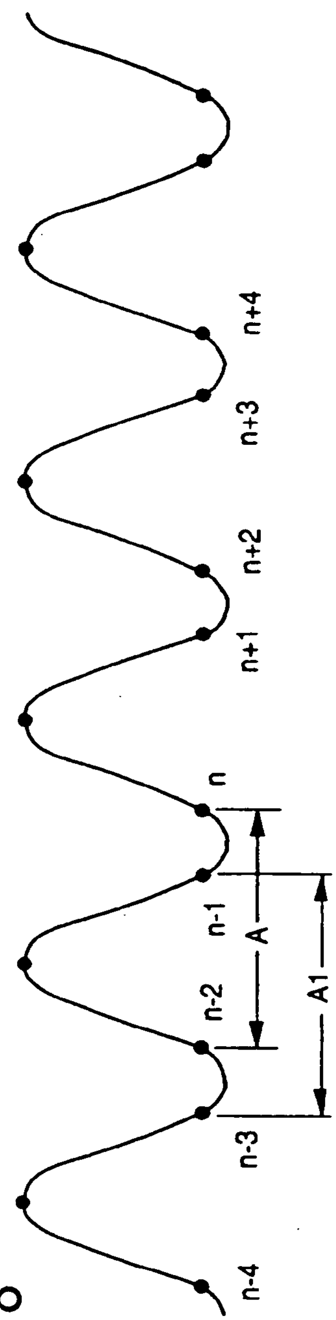


FIG - 9

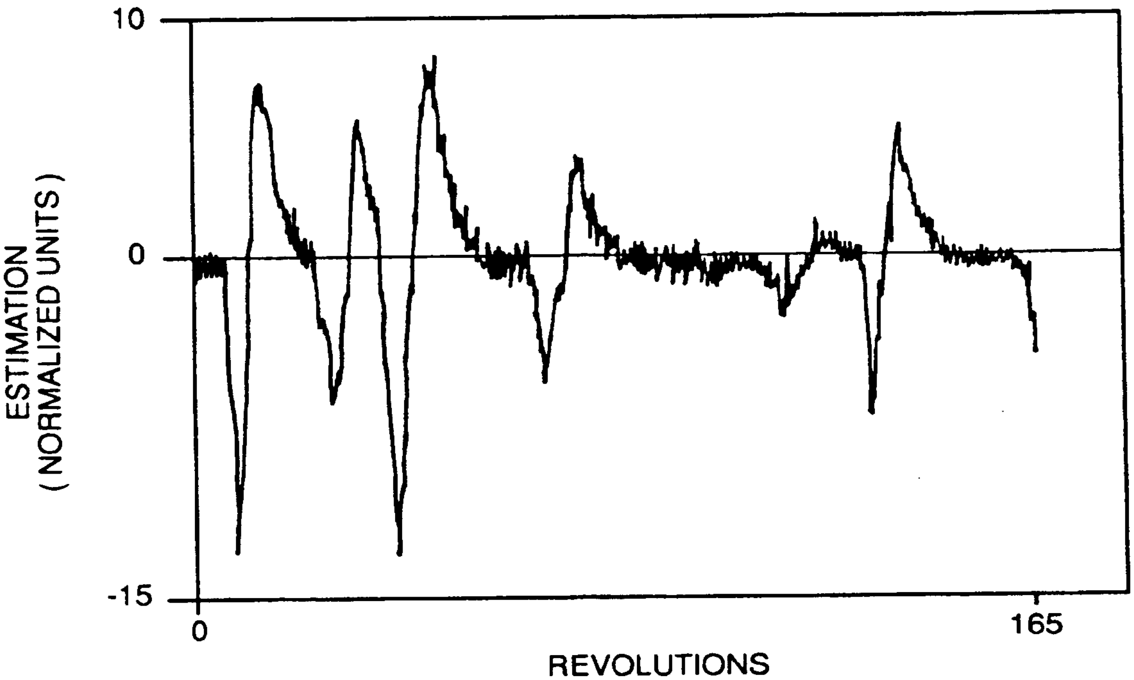

10
0
-15
ESTIMATION
(NORMALIZED UNITS)
0
165
REVOLUTIONS

FIG - 10

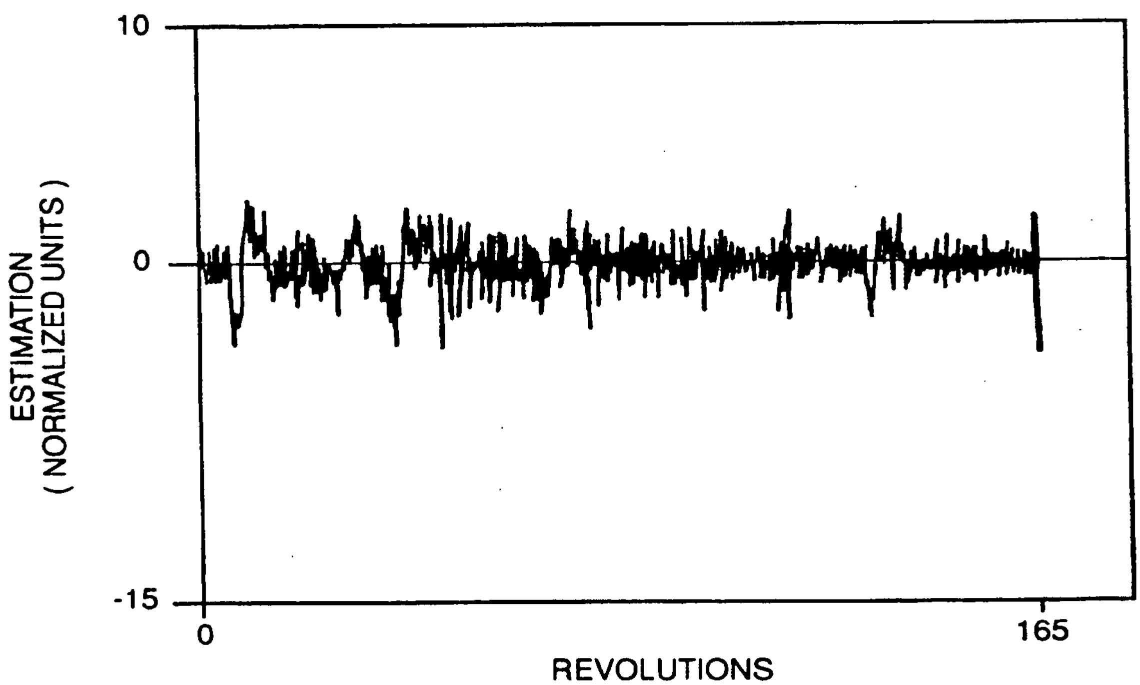
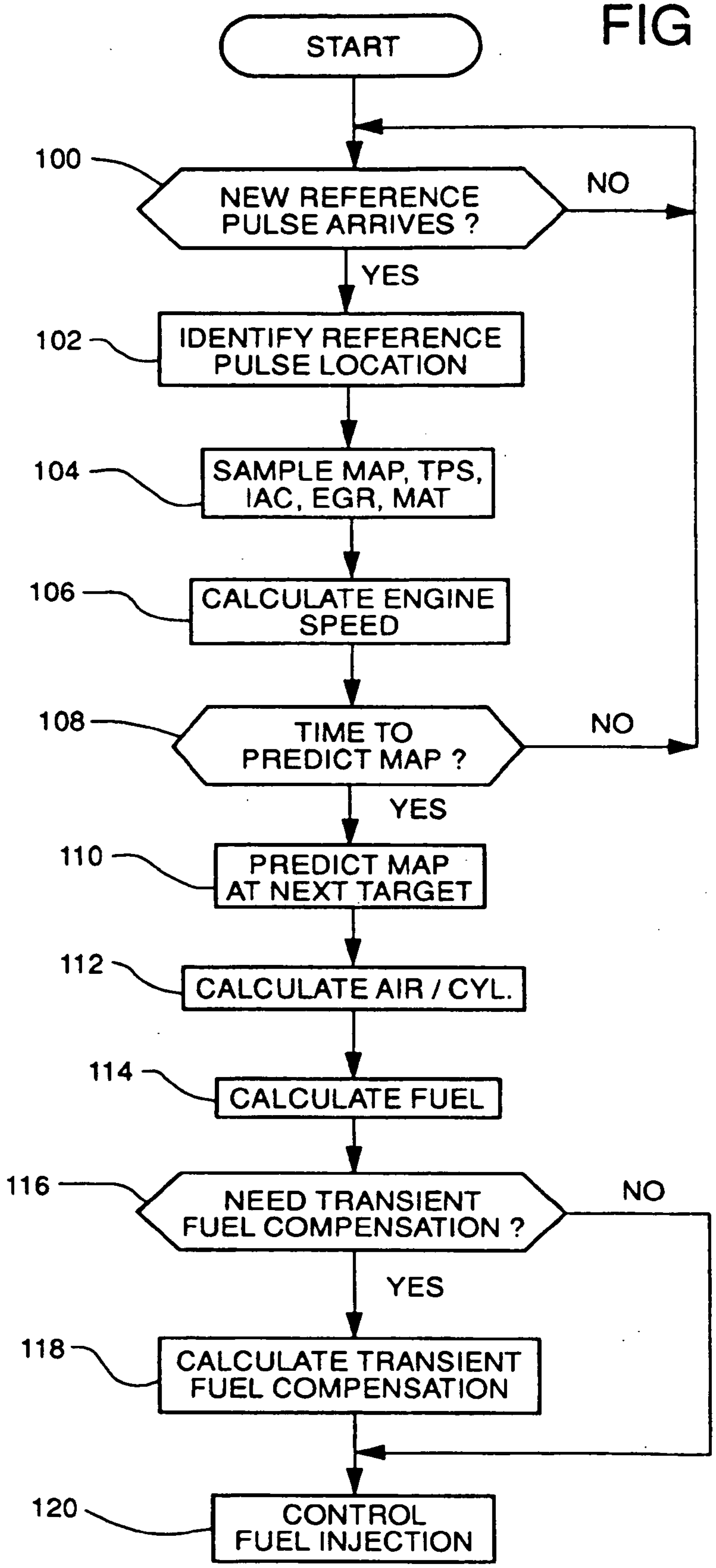

10
0
-15
ESTIMATION
(NORMALIZED UNITS)
0
165
REVOLUTIONS

FIG - 11


START
100
NEW REFERENCE PULSE ARRIVES ?
NO
YES
102
IDENTIFY REFERENCE PULSE LOCATION
104
SAMPLE MAP, TPS, IAC, EGR, MAT
106
CALCULATE ENGINE SPEED
108
TIME TO PREDICT MAP ?
NO
YES
110
PREDICT MAP AT NEXT TARGET
112
CALCULATE AIR / CYL.
114
CALCULATE FUEL
116
NEED TRANSIENT FUEL COMPENSATION ?
NO
YES
118
CALCULATE TRANSIENT FUEL COMPENSATION
120
CONTROL FUEL INJECTION

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93202674.3

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US - A - 4 987 888 (FUNABASHI et al.) * Abstract; claims, fig. 1-4 * --	1,9	F 02 D 41/18 F 02 D 41/26 F 02 D 41/04
A	EP - A - 0 476 811 (FORD) * Abstract; claims; fig. 1 * --	1,9	
A	US - A - 5 003 950 (KATO et al.) * Abstract; claims; fig. 5-7,15,16 * ----	1,9	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

F 02 D 41/00
F 02 P 5/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	24-11-1993	KUTZELNIGG

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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L : document cited for other reasons

& : member of the same patent family, corresponding document